CHAPTER 10

Sensitivity Analysis

Summary

This chapter explores the effects of varying some of the assumptions that were used to develop the investment scenario projections in Chapter 7. In any modeling effort, evaluating the validity of the underlying assumptions is critical. The results produced by the Highway Economic Requirements System (HERS) and the Transit Economic Requirements Model (TERM) are strongly affected by the values they are supplied for certain key variables. This chapter was first added to the 1999 C&P report to open up more of the modeling process and to make the report more useful for supplementary analysis efforts.

The first part of this chapter addresses the impacts that aggressive congestion reduction strategies could have on the future investment scenario estimates. Two alternatives involving intelligent transportation systems (ITS) and operations strategies are developed. The first assumes a more aggressive deployment schedule than the one assumed in the baseline scenarios, which was based on existing trends. The second is a hypothetical scenario that assumes full, immediate deployment, illustrating the maximum impact that the technologies and strategies modeled in HERS would be expected to have. The third illustrative scenario assumes the universal application of efficient pricing on all congested roads. By aligning the costs borne by highway users with the costs they impose on other users, such policies can encourage the more efficient use of the transportation system.

One of the major enhancements to the HERS modeling process in this report is to account for the amount of additional revenue that would be required to support higher levels of investment. The chapter shows the impact of this new feature, as well as the impact of accounting for work zone delay, a new type of user impact in HERS that was introduced in the 2004 edition.

There is some uncertainty about the 20-year travel growth forecasts on which HERS and TERM rely. The highway and transit sections both show the impact of changing assumptions about growth rates on the investment scenario projections. Highway investment scenario estimates are shown for an alternative in which baseline constant-price future highway travel growth rates match those observed over the last 20 years. The sensitivity of the transit investment scenario estimates to the growth rate forecast is analyzed by allowing three alternative growth rate inputs: 50 percent higher than the forecast, 50 percent below the forecast, and 100 percent below the forecast (i.e., zero transit passenger-mile growth). Transit investment scenarios are also calculated using the 1.5 percent passenger miles traveled (PMT) forecast in the 2004 C&P report.

The chapter also includes other sensitivity analyses that show the impact of using alternative values for certain key model parameters (whose estimated values may be subject to some uncertainty). Both the highway and transit sections analyze the impact of increasing the unit improvement costs in the three investment models by 25 percent, as well as the effects of variations in the value of time and travel demand elasticity. The highway section also considers alternative values for additional parameters, including the value of a statistical life and the value of reducing incident delay. The transit section looks at the effect of making performance-enhancing investments in light rail instead of in bus rapid transit (BRT), and at changing the replacement threshold for guideway (a revision made for this report).

Highway Sensitivity Analysis

The accuracy of the investment scenario estimates reported in Chapter 7 depends on the validity of the underlying assumptions used to develop the analysis. This section explores the effects that varying several key assumptions in the highway investment analysis process would have on the Maximum Economic Investment (Cost to Improve Highways and Bridges) and the Cost to Maintain Highways and Bridges. While not discussed directly in this chapter, any changes in the projected investment scenarios would also affect the gaps identified in Chapter 8 between projected spending and the investment scenario levels.

Aggressive Congestion Reduction Strategies

As described in Chapter 7, the HERS analysis considers the impact of current and future ITS deployments and operations strategies on highway conditions and performance, with resulting implications for the projected investment scenario levels. The analyses of Chapters 7, 8, and 9 used a baseline scenario for future deployments based on existing trends. Chapter 7 and Appendix A include more information on the types of strategies and investments reflected in the existing trends deployment scenario, which include those targeted at freeway management (ramp metering, electronic monitoring, variable message signs, and traffic management centers), incident management (incident detection, verification, and response), and arterial management (upgraded signal control, electronic monitoring, variable message signs, and emergency vehicle signal preemption).

The baseline scenarios assume the continuation of existing financing structures. As a result, the inherent economic inefficiencies of the current structure would remain, whereby travel on uncongested facilities is charged at the same rate as those with significant congestion issues. In an ideal (from an economic point of view) world, users of congested facilities would be levied charges precisely corresponding to the economic cost of the delay they impose on one another, thereby reducing peak traffic volumes and increasing net benefits to all users combined.

The analyses in this section explore the impact that alternative assumptions about future ITS deployments and more efficient pricing could have on the baseline investment analysis results.

Operations/ITS Deployment

Exhibit 10-1 shows the impact of two alternative operations and ITS deployment scenarios: one with more aggressive assumptions about future deployments, and a hypothetical scenario that assumes full, immediate deployment of selected operations/ITS strategies in all urban areas. Appendix A includes more information on how these scenarios were defined.

The aggressive operations/ITS deployment scenario assumes that existing trends in the adoption of ITS infrastructure and strategies would accelerate in the future. The impact of increasing the rate at which such technologies are adopted in the future would be to decrease the estimated infrastructure investment necessary to maintain conditions and performance at current levels by approximately $1.9 billion per year under this particular scenario. While this reduction is small in overall percentage terms (2.4 percent of the total Cost to Maintain Highways and Bridges), it should be considered that the impacts are concentrated on capacity investments in urbanized areas. In 2004, such investments accounted for just one-fifth of total highway capital outlay.

Exhibit 10-1

Impact of Aggressive Congestion Reduction Strategies on Investment Scenario Estimates

	Cost to Maintain Highways & Bridges		Maximum Economic Investment for Highways & Bridges	
	($Billions)	Percent Change	($Billions)	Percent Change
Chapter 7 Baseline	**$78.8**		**$131.7**	
Aggressive Operations Deployments	$76.9	-2.4%	$131.1	-0.5%
"Full" Operations Deployments	$73.6	-6.6%	$131.9	0.1%
"Universal" Congestion Pricing	$57.2	-27.5%	$110.8	-15.9%

Source: Highway Economic Requirements System (HERS).

Q&A

What are the costs associated with the aggressive deployment strategy analyzed here, relative to those for the baseline existing trends deployment strategy?

As described in Chapter 7, the costs of the new or increased operations deployments include both the capital costs of the equipment and infrastructure and the ongoing costs of operating and maintaining that infrastructure. The costs include those for both the basic infrastructure needed to support a given strategy (such as a traffic operations management center) and the incremental costs of increasing the coverage of that structure (such as additional ramp meters).

The estimated average annual capital cost of new deployments under the aggressive deployment strategy used for these analyses is $590 million (in 2004 dollars). These costs are included in the capital investment scenario estimates based on the aggressive deployment strategy shown in Exhibit 10-1 for both the "Cost to Maintain" and "Maximum Economic Investment" scenarios. As described in Chapter 7, the comparable figure for the baseline existing trends deployment strategy was $94 million per year.

Estimated average annual operating and maintenance costs for the aggressive deployment strategy over the same 2005 to 2024 time period are $3.2 billion (in 2004 dollars), including $890 million for new deployments and $2.3 billion for the existing infrastructure. These costs **are not** included in the Cost to Maintain or the Maximum Economic Investment figures in Exhibit 10-1. As described in Chapter 7, the comparable figure associated with the baseline existing trends strategy was $2.7 billion, including $260 million for new deployments and $2.5 billion for the existing infrastructure.

Note also that the costs shown above reflect only the particular types of improvements currently modeled in HERS, and thus represent a subset of total operations deployments that are expected to occur. This analysis attempts to capture other capital costs relating to operations control facilities via the external adjustment procedure for non-modeled improvement types discussed in Chapter 7.

The average annual capital cost of new deployments under the hypothetical full deployment scenario would be $1.2 billion. However, as this scenario assumes the immediate and complete deployment of all ITS technologies and operations strategies, these costs would be entirely front loaded at the beginning of the analysis period.

The aggressive scenario does not have as significant an impact on the Maximum Economic Investment relative to that based on existing trends, reducing that level by less than 1 percent. While ITS deployments would in some cases reduce the benefit-cost ratio (BCR) of certain potential widening projects below the 1.0 threshold imposed by this scenario, in other cases, both an ITS deployment and a widening project would be cost-beneficial. Consequently, the level of performance that HERS finds cost-beneficial to achieve would be significantly better under the aggressive scenario than under the baseline trends scenario. Average highway user costs would be lower than under the existing trends scenario, representing additional annual savings of $10 billion by 2024 ($126 billion in annual savings relative to 2004, compared with $116 billion under the existing trends scenario). Incident delay costs on urban arterials and collectors would be reduced by another 2.9 percent (and by 5.4 percent on urban Interstates) relative to the baseline scenario, even though the overall level of investment is lower.

The "full deployment" scenario illustrates the maximum impact that the types of strategies and technologies modeled in HERS could have on the future investment scenario estimates. Deploying ITS to the fullest extent would have a strong impact on the Cost to Maintain Highways and Bridges, reducing it by $5.2 billion (6.6 percent). While the Maximum Economic Investment level with full deployment is essentially the same as for the baseline scenario, the impact on highway conditions and performance is even greater than under the aggressive deployment scenario. Annual highway user cost savings in 2024 would be $27 billion more than under the baseline scenario ($144 billion in annual savings compared with 2004), and incident delay costs on all arterials and collectors in urban areas would be reduced by 4.1 percent (6.9 percent on urban Interstates).

Congestion Pricing

As referenced throughout this report, the baseline investment scenarios assume the continuation of existing financing structures, under which user fees are typically assessed on a per-mile (or per-gallon) basis. As a result, highway users are typically charged the same amount, regardless of where or at what time of day they travel. As discussed in the Introduction to Part II, this can contribute to overuse of the transportation system, since users of congested roads are paying the same rate as those on uncongested routes. The efficiency of the system could be improved by imposing congestion-based tolls, which could be set at a level at which users of congested facilities would pay a cost equivalent to the negative impact that their use has on other drivers.

The HERS model has recently been modified to simulate the imposition of optimal congestion pricing on congested roadways. Preliminary results from these new procedures are shown in Exhibit 10-1. There are numerous caveats that should be understood when interpreting these results. The scenario should be considered to show the impact that optimal, universal congestion pricing could have on the investment scenario estimates. **This theoretical scenario does not constitute a comprehensive policy proposal.** The analysis does not account for the substantial startup and administrative costs that could be associated with deploying congestion pricing on a universal basis, which could vary widely depending on the type of technology adopted to collect them. The congestion tolls applied in the analysis would be

Q&A

What are the limitations of the preliminary HERS pricing analysis presented in this section?

The primary limitation of the analysis is that it assumes that efficient prices could be charged universally, on all functional classes, during the entire analysis period. As discussed in the Introduction to Part II, a number of barriers exist to the implementation of a perfectly efficient congestion pricing system in the real world. Calculating and collecting tolls impose costs on both operators and users of a toll facility, and achieving the true optimum would require both a comprehensive knowledge of user demand and the ability to continuously monitor congestion and dynamically adjust the fees that motorists are charged.

The current state and extent of pricing technology and infrastructure are also limited. Variable tolling systems are much more practical at bridges, tunnels, or on freeways; deploying such systems on surface arterials and collectors, with numerous access points and intersecting traffic, would be much more challenging, depending on the type of technology used. However, new technologies are being developed and considered that could make more widespread adoption of such approaches more practical in the future.

The analysis is also limited by the current HERS modeling framework. The model treats highway segments independently and does not account for the full general-equilibrium impacts of pricing on interconnected roadways. Additional refinements would also be required to more completely model the shifting of demand between time periods.

Q&A

How high are the congestion tolls being imposed by HERS in the analysis described in this section, and what would be the associated revenues?

The average congestion toll calculated by HERS on highway sections where it is applied is 20.5 cents per mile for the "Maintain" scenario and 17.4 cents per mile for the "Maximum Economic Investment" scenario. On some extremely congested sections, the optimal congestion tolls can be considerably higher, while the optimal congestion tolls would be lower on less congested sections. No congestion tolls were applied to uncongested highway sections. The estimated annual revenues produced by the congestion tolls are approximately $34 billion for the "Maintain" scenario and $24 billion for the "Maximum Economic Investment" scenario. Average toll rates and annual revenues would be higher in the latter portions of the 20-year analysis period, as baseline traffic levels increase and contribute to congestion.

The larger average tolls and revenues under the "Maintain User Cost" scenario reflect the fact that higher tolls are required at lower levels of highway investment to suppress travel to the point that user costs would be maintained. Congestion would be higher under this scenario, so that drivers have larger negative impact on each other. For the "Maximum Economic Investment" scenario, the additional capacity expansion at the higher investment levels result in reduced congestion, so that drivers' impact on each other is not as severe, and thus the efficient congestion toll rates are lower.

As is noted in the text, the investment analysis with congestion pricing applied were not revenue constrained, as in the baseline analysis. However, this analysis suggests an important dichotomy between the revenues that would be produced under congestion pricing and revenues that would be generated from user fees to fund increased investment levels; in fact, the two are in some sense counter to one another. Lower levels of investment would require smaller user fee charges, but would result in more congestion and thus higher efficient congestion tolls and revenues. Higher levels of investment would require larger user fee charges, but congestion levels, toll rates, and revenues would be lower. While revenues from congestion pricing would be available to finance capital investment, they are not explicitly intended for that purpose, and this is reflected in the efficient toll rates that would be applied in this analysis.

in addition to any current user taxes and fees; they do not substitute for existing fees. This analysis represents an initial attempt at quantifying some of the impacts of congestion pricing; future research is planned to refine this analysis to more explicitly consider time of day demand shifts and to better account for some of the network effects among parallel or intersecting routes. However, there will always be limits on how well a segment-based model such as HERS can model these effects (see the discussion of this topic in the Part IV Afterword).

The results of this hypothetical HERS analysis shown in Exhibit 10-1 indicate that **universal congestion pricing would have a very significant impact** on the investment scenario estimates. The Maximum Economic Investment level would decrease by almost 16 percent, to $110.8 billion. The estimated "gap" between this scenario and 2004 highway capital outlay would be reduced to 57.7 percent. The Cost to Maintain Highways and Bridges would decline even more proportionally, by over 27 percent, to $57.2 billion. This level of investment is well below 2004 capital spending.

While this analysis uses a theoretical, idealized construct (universal pricing at economically efficient levels) and may thus potentially overstate the impact to some degree, it nevertheless indicates that pricing, in conjunction with operations strategies and other highway investment, has a very important and potentially substantial role to play in addressing highway congestion. Future refinements planned for this line of analysis could result in either higher or lower estimates of the impacts shown in this initial attempt at modeling congestion pricing in the C&P report.

Impact of Recent Model Enhancements

As new capabilities and enhancements are made to the C&P analytical tools in each report, it is useful to document the impact that these new features have on the investment scenario estimates. A new HERS feature introduced in this report links highway revenues with highway investment. The investment scenario estimates in the 2004 C&P report included the effects of work zone delay in the estimates of user benefits. However, since that report did not document the impact of this feature, such an analysis is included here.

Linking Revenue and Investment

One of the primary changes to the highway investment methodology is to link the investment analyses to the revenues that would be required to support such a level of investment. Chapter 7, Appendix A, and the Introduction to Part II have more extensive discussions of this feature, which assumes that increases in annual highway capital investment above base year 2004 levels would be financed through increases in highway user charges. By raising the cost of highway travel, such surcharges have the effect of reducing future travel growth and the level of investment required to support it.

Exhibit 10-2 shows the impact that this new feature has on the future investment estimates under the two scenarios presented in Chapter 7. "Turning off" the revenue option feature in HERS (thereby ignoring the link between revenue and investment) would increase the estimated Cost to Maintain Highways and Bridges by 2.6 percent ($2.1 billion). The impact on the "Maximum Economic Investment" scenario would be even larger, at 3.7 percent ($4.9 billion higher than the baseline scenario). As the "gap" between current spending and the level of investment under the scenarios increases, so does the level of the required user surcharge to align revenues and investment. As a result, the impact of this feature is proportionally greater at the Maximum Economic Investment level than at the Cost to Maintain level.

More information on this HERS feature is found in the Chapter 7, Appendix A, and the Introduction to Part II.

Exhibit 10-2

Impact of Recent Model Enhancements on Investment Scenario Estimates

	Cost to Maintain Highways & Bridges		Maximum Economic Investment for Highways & Bridges	
	($Billions)	Percent Change	($Billions)	Percent Change
Chapter 7 Baseline	**$78.8**		**$131.7**	
No Link between Revenue and Investment	$80.9	2.6%	$136.6	3.7%
No Work Zone Delay	$78.3	-0.6%	$133.5	1.4%

Source: Highway Economic Requirements System (HERS).

Work Zone Delay

For the 2004 C&P report, HERS was modified to consider the negative impact that work zones would have on existing users of the road, modeled as the delay (due to reduced capacity) associated with highway improvements. The work zone delay estimates are included as a negative user benefit in the HERS benefit-cost analysis. Appendix A of the 2004 C&P report contains more information on this feature.

"Turning off" this feature by removing it from the HERS BCR calculations has a modest impact on the scenario estimates. Exhibit 10-2 indicates that ignoring work zone delay impacts would increase the

Maximum Economic Investment level by 1.4 percent ($1.8 billion). Some marginal projects that are not cost-beneficial when accounting for work zone delay would become so if these effects were not included.

The estimated Cost to Maintain Highways and Bridges would decrease by 0.6 percent ($0.5 billion). Since all projects at this level of investment are well above the BCR threshold, turning work zone delay off does not result in any new projects being considered; instead, it affects only the relative ranking of potential improvements. The net impact of this is a slight shift toward capacity investment, which reduces the investment necessary to maintain user costs.

Alternative Model Assumptions

Using the HERS and National Bridge Investment Analysis System (NBIAS) models to produce the investment analyses for this report requires certain assumptions to be made concerning the nature of the data that are used and the way in which the analyses are structured internally in the models. Some of these key assumptions include the interpretation of the future travel forecasts in the data, the method used to "grow" traffic between the base year and the travel forecast year, and the temporal pattern of investment under the "Maximum Economic Investment" scenario.

Travel Growth and Price Forecasts

States provide forecasts of future vehicle miles traveled (VMT) for each individual Highway Performance Monitoring System (HPMS) sample highway section. As indicated in Chapter 7, HERS assumes that the forecast for each sample highway segment represents the level of travel that will occur if a constant level of service is maintained on that facility. This implies that VMT will occur at this level only if pavement and capacity improvements made on the segment over the 20-year analysis period are sufficient to maintain highway user costs (exclusive of taxes and tolls) at 2004 levels. If HERS predicts that highway-user costs will deviate from baseline 2004 levels on a given highway segment, the model's travel demand elasticity features will modify the baseline VMT growth projections from HPMS. Appendix A includes more discussion of the travel demand elasticity features in HERS.

The HERS model utilizes VMT growth projections to predict future conditions and performance of individual highway segments and to analyze future investment. If the HPMS VMT forecasts *as modified by the HERS travel demand elasticity features* are overstated, the investment scenario projections may be too high. If travel growth is underestimated, the investment scenario estimates may be too low.

The effective VMT growth rates predicted by the HERS model could be off target if (1) the HPMS forecasts don't precisely represent the travel that will occur if a constant level of service is maintained or (2) the travel demand elasticity procedures in HERS don't accurately predict how highway users will respond to changes in costs. The latter effect is addressed in the next section by varying the values of the elasticity parameters used in the model. This section explores the impacts of the former case by modifying the estimates of future travel found in the HPMS sample data.

As indicated in Chapter 9, the State-supplied VMT growth projections in HPMS for 2004 to 2024 average 1.92 percent per year, well below the 2.76 percent average annual VMT growth rate observed from 1984 to 2004. The HERS model assumes that the 1.92 percent composite VMT growth projection in HPMS represents the growth that will occur at a constant level of service. As noted in Chapter 4, however, the level of service on highways in the United States has generally been declining over the past two decades. If States expect this trend to continue and factor this into their projections, then the HPMS forecasts might represent a declining level of service as well, and would thus understate future *constant price* growth, causing HERS to likewise underestimate the level of investment that would be needed to achieve a given level of performance.

It is thus prudent to consider the impact of such a circumstance on the Chapter 7 projections, and the historic growth rate provides a useful benchmark for comparison.

Exhibit 9-7 shows the impact of different levels of future investment on the average annual VMT growth rate, if one assumes that the baseline travel growth forecasts in HPMS represent a constant level of service. *Exhibit 10-3* shows the impact on the investment scenario estimates of assuming that the 20-year future growth in VMT that would occur at a constant level of service matches the growth over the previous 20 years, rather than using the baseline assumption that the constant-price growth would be in line with the HPMS forecasts. Modifying the travel growth projections in this fashion would increase the Cost to Maintain Highway and Bridges by 56.6 percent. Increased VMT would increase the rate of pavement deterioration, as well as increase the share of resources that HERS would recommend using for capacity expansion, to nearly 50 percent of total highway investment under this scenario. Both of these factors would tend to increase the investment that would be necessary to maintain user costs at 2004 levels.

The Maximum Economic Investment for Highways and Bridges would increase by 33.9 percent based on this change in assumptions. The increased travel would increase the number of pavement and capacity projects that HERS would find cost-beneficial.

Q&A

Can Exhibit 10-3 be used to analyze the impact that travel demand management policies (such as pricing) have on the investment scenario estimates?

No. Travel demand management (TDM) policies are intended to actively reduce the amount of highway usage in congested periods. Such policies accomplish this goal by directly or indirectly raising the cost of highway travel to users in order to alleviate excess demand and are often used as a means of addressing inefficiencies in the pricing of highway use (see the discussion in the Introduction to Part II). As discussed in Chapter 7, the travel demand elasticity feature of HERS is intended to capture the effect of increases or decreases in the price of travel on travel demand. This is not what the figures shown in Exhibit 10-3 represent, however. Rather, they simply convey the impact that different assumptions about future constant-price travel growth would have on the investment estimates and should thus not be used to make inferences about changes in VMT growth rates induced by TDM strategies.

More generally, Exhibit 10-3 should not be used to infer a direct linear relationship between a certain level of future VMT and future highway investment. This relationship is not linear, and the overall level of future travel nationwide is less critical than the spatial distribution of future travel growth. For example, large increases in VMT on uncongested highway sections would not impact the future investment scenario estimates as much as smaller increases in VMT on severely congested highway sections.

Another assumption concerning future travel growth that is made in the HERS analysis concerns the pattern of growth between the base year of the analysis and the future year of the travel forecasts in HPMS. The assumption used in the baseline scenarios is that growth

Exhibit 10-3

Impact of Alternate Model Assumptions on Investment Scenario Estimates

	Cost to Maintain Highways & Bridges		Maximum Economic Investment for Highways & Bridges	
	($Billions)	Percent Change	($Billions)	Percent Change
Chapter 7 Baseline	**$78.8**		**$131.7**	
Historic VMT Growth Rates	$123.5	56.6%	$176.4	33.9%
Geometric VMT Growth	$87.5	11.0%	$132.7	0.8%
Minimum BCR			$129.1	-2.0%

Source: Highway Economic Requirements System (HERS).

will occur at a constant annual level. This is sometimes referred to as *linear growth*. An alternative assumption would be that travel growth occurs at a constant annual rate, often referred to as *geometric growth*. Linear growth implies a declining annual growth rate over time. The "Travel Growth Forecasts" section in Chapter 9 discusses these two different assumptions about future growth patterns.

The impact of assuming a geometric growth pattern in the HERS travel forecasts is shown in Exhibit 10-3. The estimated Cost to Maintain Highways and Bridges level would be higher under this assumption, increasing 11 percent relative to the baseline scenario. VMT levels in earlier funding periods are lower under the geometric growth assumption than under the linear growth assumption. However, in later years, this situation is reversed, as VMT under geometric growth continues to rise exponentially and greatly exceed the levels under constant annual growth through 2024 and beyond. Since the potential highway improvements identified by HERS consider future travel growth for the lifetime of the improvement, the higher VMT growth beyond 2024 would affect the pattern of investments recommended by the model. The share of investment devoted to capacity expansion under this alternative assumption would rise to over 42 percent of total capital spending, and the cost of attaining any fixed level of system performance in 2024 (such as the Cost to Maintain level) would be more expensive. The impact of assuming a geometric growth pattern in the HERS travel forecasts on the Maximum Economic Investment level would be smaller, since this scenario does not target a specific level of system performance. Under this assumption, the Maximum Economic Investment level would increase by 0.8 percent relative to the baseline scenario.

Timing of Investment

In previous editions of the C&P report using the HERS model for the highway investment analysis, the Maximum Economic Investment for Highways and Bridges (Cost to Improve) was defined by setting the minimum BCR threshold in the model at 1.0 and implementing all improvements with BCR's exceeding this threshold. The effect of this model setting was to front-load the investment projected in HERS, as the entire backlog of cost-beneficial investments was addressed in the first 5-year funding period, followed by lower levels of expenditures meeting the benefit-cost test in subsequent funding periods. The total investment over all the periods was then converted to an average annual figure for use in the report.

For this edition of the report, the structure of this HERS scenario has been modified. The Maximum Economic Investment level is now defined as the highest constant level of annual investment that can be attained while continuing to only implement improvements in each funding period that are cost-beneficial. This change was made to facilitate the use of the new revenue options feature in HERS described above, in which user charges are linked to annual investment levels.

The impact of this change is to increase the estimated level of investment under this scenario. Defining the Maximum Level of Investment under the old BCR test would result in an average annual investment estimate of $129.1 billion, which is $2.6 billion (or 2.0 percent) lower than the baseline amount reported in Chapter 7. The significance of this difference is that, by aggressively investing in highways over the first 5 years, the total amount of cost-beneficial investment (in constant 2004 dollars) over 20 years would be reduced. This $2.6 billion annual difference could be interpreted as a "cost" of deferred investment in highways.

Alternative Model Parameters

The HERS model uses several key input parameters whose values may be subject to considerable uncertainty or debate, but whose values can affect the costs and benefits of investment strategies estimated within the model. To assess the importance of such uncertainty, the future investment scenario estimates were recomputed using different values for some of these parameters, including the unit costs of highway and bridge capital improvements and HERS values for a statistical life, ordinary travel time, reductions in incident delay, and travel demand elasticity. *Exhibit 10-4* shows the impacts of the alternative parameter values on the Maximum Economic Investment level for Highways and Bridges.

Exhibit 10-4

Impact of Alternate Model Parameters on Investment Scenario Estimates

Maximum Economic Investment for Highways & Bridges	($Billions)	Percent Change
Chapter 7 Baseline	**$131.7**	
HERS and NBIAS Improvement Costs		
Increase 25 percent	$146.4	11.2%
Value of a Statistical Life		
Reduce 50 percent	$130.7	-0.8%
Increase 100 percent	$133.5	1.4%
Value of Ordinary Travel Time		
Increase 25 percent	$139.1	5.6%
Reduce 25 percent	$122.3	-7.2%
Value of Incident Delay Reduction		
3 times value of ordinary travel time	$139.4	5.8%
Equal to value of ordinary travel time	$122.0	-7.4%
Elasticity Values		
Use 2004 C&P values	$123.0	-6.6%

Source: Highway Economic Requirements System.

Improvement Costs

The unit improvement costs used in HERS and NBIAS to calculate total investment costs, though recently updated, may themselves be subject to uncertainty. For example, currently unforeseen circumstances may cause highway construction costs to increase faster than the general rate of inflation in the future. It is therefore prudent to consider the impact of higher-than-expected capital improvement costs on the estimated investment levels under the C&P scenarios.

While this particular sensitivity analysis has been routinely included in each of the previous three editions of the C&P report, it has taken on even more meaning in light of recent trends in highway construction costs, which rose sharply in 2005. As discussed in Chapter 8, trends through the first three quarters of that year showed an increase of 24 percent above 2004 levels. While the quarterly volatility in the Federal Highway Administration Bid Price Index makes it impossible to predict what final 2005 or 2006 values for that index are likely to be, anecdotal evidence suggests that these cost increases have not abated. As a result, this analysis may be viewed as reflecting actual recent trends rather than hypothetical future ones.

Exhibit 10-4 shows the impact of inflating all the improvement costs used by HERS and NBIAS by 25 percent on the Maximum Economic Investment level (note that this is a departure from the comparable scenarios in earlier C&P reports, which reflected only changes to the HERS cost inputs). The increase in the investment scenario estimates due to higher unit values for the improvement costs is partially offset by the elimination of some projects that would no longer be considered cost-beneficial by HERS or NBIAS. The net result is an increase of 11.2 percent in the scenario estimate. The impact is greater on the NBIAS results (increasing scenario costs by 18.8 percent) than in HERS (increasing scenario costs by 10.1 percent). As discussed in the Part IV Afterword, the benefit-cost tests applied in HERS are more robust than those in NBIAS, which results in relatively more potential investments being “screened out” at the higher construction cost levels.

Increasing the unit improvement costs by a given percentage has a straightforward (if less conceptually meaningful) impact on the “Cost to Maintain” scenario estimates from the two models. Since the investments included in the “Maintain User Cost” scenario all have BCRs well above 1.0, raising the improvement cost estimates does not cause HERS to forego any improvements on benefit-cost grounds. Similar effects would result in the “Maintain Economic Backlog” scenario in NBIAS. The increase in the Cost to Maintain Highways and Bridges will thus be roughly proportional to the change in improvement costs.

Value of a Statistical Life

HERS uses $3.0 million for the value of a statistical life, which is the U.S. Department of Transportation's (DOT's) standard value for use in benefit-cost analyses. As with the value of time, there is a great deal of debate about the appropriate value, and no single dollar figure has been uniformly accepted by the academic community or within the Federal government.

Doubling the value would increase the Maximum Economic Investment for Highways and Bridges by 1.4 percent. HERS would find a few more projects to implement on the basis of their increased safety benefits if the value of life were increased. Reducing the value of a statistical life by 50 percent would reduce the Maximum Economic Investment level by 0.8 percent. A few marginal projects that were justified based on potential reductions in crash rates would not be implemented if the value of life used in the analysis were reduced.

Changing the value of a statistical life in HERS does not have a significant impact on the investment scenario estimates. The model is not currently equipped to consider all the safety benefits of highway improvements, nor does it model safety-oriented enhancement projects (such as improved crash barriers or protected turning lanes). The Afterword in Part IV of this report includes a discussion of future research options for improving the HERS model's capabilities in this area.

Value of Ordinary Travel Time

The value of time in HERS was developed using a standard methodology adopted by DOT. This methodology provides consistency among different analyses performed within the Department. However, some debate remains about the appropriate way to value time, and no single methodology has been uniformly accepted either by the transportation community or within the Federal government.

Increasing the value of ordinary travel time in HERS by 25 percent would increase the Maximum Economic Investment level by 5.6 percent. Increasing the value of time causes HERS to consider more widening projects (which reduce travel time costs) to be cost-beneficial. The share of investment devoted to capacity expansion would thus increase slightly, to over 46 percent of total improvement costs (versus 44.6 percent in the baseline). Reducing the value of time by 25 percent would have the opposite effect, resulting in a 7.4 percent reduction in the Maximum Economic Investment level.

Value of Incident Delay Reduction

As noted in Appendix A and elsewhere in this report, HERS calculates the delay associated with traffic incidents in addition to that caused by recurring congestion and traffic signals. Research has indicated that such unpredictable delay may be perceived by highway users as more onerous (and thus more "costly" on a per-hour basis) than is the predictable, routine delay typically associated with peak traffic volumes. The HERS model accounts for this by allowing for a user-specified parameter for the "reliability premium" associated with reductions in incident delay, which is expressed as a multiple of the value of ordinary travel time.

The investment scenario estimates in Chapters 7 and 8 used a baseline value of 2.0 times the value of ordinary travel time for the reliability premium, which was chosen on the basis of available research. Exhibit 10-4 shows the impact of setting this premium at a higher level (3.0 times the ordinary travel time) or eliminating it by setting the value of incident delay equal to ordinary travel time.

Changing the reliability premium associated with incident delay reductions has an effect similar to changing the value of ordinary travel time. Increasing the reliability premium to 3.0 makes incident delay-reducing improvements relatively more valuable, thereby raising the Maximum Economic Investment level by 5.8 percent. Eliminating the premium results in a reduction of 7.2 percent in the investment estimate.

Elasticity Values

HERS applies both short-run and long-run travel demand elasticity procedures in its analysis, using assumed input values for these parameters. There is considerable uncertainty, however, about what the appropriate values would be in this context. The elasticity values used in the analyses for this report (-0.4 for short-run elasticity and -0.8 for long-run elasticity) are lower than the comparable parameter values that were used in the 2004 C&P report (-0.6 for short-run elasticity and -1.2 for long-run elasticity). Appendix A includes a description of the HERS elasticity procedures and the reasons for using a lower value in this report.

Using the former parameter values would reduce the Maximum Economic Investment level for Highways and Bridges by 6.6 percent. Reducing the assumed amount of travel induced by reductions in user costs at higher investment levels serves to reduce the number of projects that would be cost-beneficial.

Q&A

What impacts do alternate parameter assumptions have on the Cost to Maintain Highways and Bridges?

The impacts of alternative model parameters and procedures on the investment scenario estimates are much more ambiguous and difficult to interpret for the "Cost to Maintain Highways and Bridges" than is the case for the "Maximum Economic Investment" scenario. This generally results from the definition of the Cost to Maintain Highways and Bridges used in this report [*see Chapter 7*]. The HERS-modeled portion of this cost is based on the "Maintain User Cost" scenario, in which investment is sufficient to allow average highway user costs for 2024 as calculated by HERS to match the initial levels in 2004. The initial calculation of user costs, however, is directly affected by many of the parameters shown in Exhibit 10-4, including the values of time, incident delay, and statistical life. As a result, the target average user cost that is maintained will be different for alternative values of these parameters, leaving the baseline and the alternatives less comparable to one another and making any such comparisons less meaningful. The impacts of alternative values on the Maximum Economic Investment level, however, are based on implementing only cost-beneficial projects and are thus not subject to this same caveat.

In the case of the ordinary travel time and reliability premium parameters, increasing their value also increases the initial calculated value of user costs. Less investment would then generally be necessary to maintain user costs at this higher, less "ambitious" level in the future. In both cases, the change is somewhat artificial and due solely to differences in the specification of the baseline and alternative scenarios. Changing the value of the statistical life parameter does not affect the estimate of the "Cost to Maintain" scenario to any significant degree.

Conceptually, the values of the elasticity parameters should not affect the investment if user costs are maintained at their current levels, since there would be no price response under such circumstances. However, this would only apply to the "Maintain User Cost" scenario if this were true for every section in every time period. In fact, the scenario definition is based on system-wide averages, in which user costs will rise on some sections and decline on others. The net effect of changing elasticity parameters thus depends on how such effects play out on individual sections, making it impossible to predict the net outcome. Also, if user costs are higher or lower than the baseline in the intermediate years between the base year and the end of the 20-year analysis period, then elasticity will have stronger or lesser impacts on overall travel growth and thus investment levels under the "Maintain User Cost" scenario, but this is not directly related to elasticity and the investment level required to reach the original user cost level in the final year.

Transit Sensitivity Analysis

This section examines the sensitivity of projected transit investment estimates by the Transit Economic Requirements Model (TERM) to variations in the values of the following exogenously determined model inputs:

- Passenger miles traveled (PMT) on transit
- Capital costs
- Type of performance enhancing investment
- Replacement condition thresholds
- Value of time
- User travel cost elasticities.

These alternative projections illustrate how the baseline investment estimates for transit presented in Chapter 7 will vary in response to changes in the assumed values of input variables.

Changes in PMT

TERM relies heavily on forecasts of PMTs in large urbanized areas. These forecasts are the primary driver behind TERM's estimates of the amount of investment that will be needed in the Nation's transit system to maintain performance, i.e., current levels of passenger travel speeds and vehicle utilization rates, as ridership increases. PMT forecasts are generally made by metropolitan planning organizations (MPOs) in conjunction with projections of vehicle miles traveled as a part of the regional transportation planning process. These projections incorporate assumptions about the relative growth of travel on transit and in private vehicles in a metropolitan area. The average annual growth rate in PMT of 1.57 percent used in this report is a weighted average of the most recent, primarily 2000 to 2005, MPO forecasts available from 92 of the Nation's largest metropolitan areas. TERM investment estimates in the 2004 C&P report were based on a projected PMT growth rate of 1.5 percent, based on a weighted average of the forecasts available from 76 of the Nation's largest metropolitan areas. PMT increased at an average annual rate of 2.23 percent between 1995 and 2004 and at an average annual rate of 0.65 percent between 2002 and 2004.

Future transit investment levels have been estimated by TERM based on four alternative projected PMT scenarios to examine the sensitivity of transit investment needs to variations in PMT *[Exhibit 10-5].* These scenarios are as follows:

(1) PMT growth is 50 percent greater than the forecast levels.

(2) PMT growth is 50 percent less than the forecast levels.

(3) PMT remains unchanged (zero growth).

(4) PMT growth is 1.5 percent, the rate used in the 2004 C&P report

Varying the assumed rate of growth in PMT significantly affects estimated projected transit investment. This effect is more pronounced under the Maintain Conditions and Performance scenario than under the

Exhibit 10-5

Impact of Alternative PMT Growth Rates on Transit Investment Estimates by Scenario*

	Annual Cost to Maintain Conditions & Performance		Annual Cost to Improve Conditions & Performance	
Annual PMT Growth Rate	**(Billions of 2004 Dollars)**	**Percent Change**	**(Billions of 2004 Dollars)**	**Percent Change**
Baseline (1.57%)	$15.75	–	$21.84	–
Increased 50% (to 2.36%)	$18.72	18.8%	$24.82	13.7%
Decreased 50% (to 0.79%)	$12.95	-17.8%	$19.03	-12.9%
Decreased 100% (to 0%)	$10.33	-34.4%	$16.40	-24.9%
Baseline 2004 Report (1.50%)	$15.55	-1.4%	$21.63	-1.0%

*Investment estimates for rural and special service vehicles are included in the totals, but are not subject to the sensitivity analysis. They account for 5 percent or less of the total.

Source: Transit Economic Requirements Model and FTA staff estimates.

Improve Conditions and Performance scenario because PMT growth rates affect primarily asset expansion costs, which comprise a larger portion of the total amount to maintain conditions and performance than the total amount to improve conditions and performance. A 50 percent increase/decrease in PMT growth will increase/decrease the cost to maintain conditions and performance by 18 to19 percent and the cost to improve conditions and performance by 13 to 14 percent. TERM estimates of future investment to maintain conditions and performance would decrease by 34 percent if PMT ceases to grow, although this is not a likely scenario.

If PMT growth were assumed to be 1.5 percent, as was assumed in the 2004 C&P report, instead of 1.57 percent as assumed in this report, the investment estimated by TERM for the Maintain Conditions and Performance scenario would be 1.4 percent lower and the investment estimated to improve conditions and performance would be 1.0 percent lower than the baseline estimates in this report.

Changes in Capital Costs

The capital costs used in TERM are based on actual prices paid by agencies for asset purchases as reported to FTA in TEAM (Transit Electronic Award and Management System) and in special surveys. Asset prices in the current version of TERM have been converted to 2004 dollars as necessary. Given the uncertain nature of capital costs, a sensitivity analysis has been performed to examine the effect that higher capital costs would have on the dollar value of TERM's baseline projected transit investment.

As shown in *Exhibit 10-6,* a 25 percent increase in capital costs increases the costs to maintain conditions and performance by 18 percent and the costs to improve conditions and performance by 15 percent.

Exhibit 10-6

Impact of a 25 Percent Increase in Capital Costs on Transit Investment Estimates by Scenario*

	Annual Cost to Maintain Conditions & Performance		Annual Cost to Improve Conditions & Performance	
	(Billions of 2004 Dollars)	**Percent Change**	**(Billions of 2004 Dollars)**	**Percent Change**
Baseline	$15.75	–	$21.84	–
Increase Costs 25%	$18.62	18.2%	$25.02	14.6%

*Investment estimates for rural and special service vehicles are included in the totals, but are not subject to the sensitivity analysis. They account for 5 percent or less of the total.

Source: Transit Economic Requirements Model and FTA staff estimates.

With this increase in costs, fewer investments are economically viable under the Improve Conditions and Performance scenario than under the Maintain Conditions and Performance scenario.

Change Performance-Enhancing Investment from BRT to Light Rail

Starting with the 2004 C&P report, TERM has assumed that investment to improve performance by increasing the speed of passenger travel in urbanized areas with populations of less than 1 million and no rail system are made in BRT. The 2002 C&P report assumed that these performance improving investments were made in light rail. As shown in *Exhibit 10-7,* the estimated investment to improve conditions and performance would be 1.4 percent higher if performance improving investments were assumed to be made in light rail instead of BRT.

Exhibit 10-7

Impact of Replacing BRT with Light Rail to Improve Estimates by Scenario*

	Annual Cost to Improve Conditions & Performance	
	(Billions of 2004 Dollars)	**Percent Change**
Baseline	$21.84	–
Light Rail Performance Enhancing Investment	$22.14	1.4%

*Investment estimates for rural and special service vehicles are included in the totals, but are not subject to the sensitivity analysis. They account for 5 percent or less of the total.

Source: Transit Economic Requirements Model and FTA staff estimates.

Changes in Replacement Condition Thresholds

Asset condition thresholds set the condition that an asset must fall to in order for TERM to make the decision to invest money to replace it. These condition thresholds are provided in Appendix C. The replacement threshold used to determine replacement investments for guideway was raised from 1.5 for the 2004 C&P investment scenarios to 1.75 for the results in this report. As shown in *Exhibit 10-8*, the estimated investment to maintain conditions would be 3.9 percent lower and the estimated investment to improve conditions would be 2.8 percent lower if guideways were allowed to deteriorate to the lower 1.5 condition.

Exhibit 10-8

Impact of Using 2004 C&P Condition Replacement Thresholds*

	Annual Cost to Maintain Conditions & Performance		Annual Cost to Improve Conditions & Performance	
	(Billions of 2004 Dollars)	**Percent Change**	**(Billions of 2004 Dollars)**	**Percent Change**
Baseline	$15.75	–	$21.84	–
2004 C&P Thresholds	$15.15	-3.9%	$21.25	-2.8%

*Investment estimates for rural and special service vehicles are included in the totals, but are not subject to the sensitivity analysis. They account for 5 percent or less of the total.

Source: Transit Economic Requirements Model and FTA staff estimates.

Changes in the Value of Time

The value of time is a key input to TERM's benefit-cost analysis and is one of the factors used to determine the level of investment in capital assets for both the "Maintain Performance" and the "Improve Performance" scenarios. The value of time is used to estimate changes in the total benefits accruing to transit users from investments in transit infrastructure that change the duration of passengers' travel time.

Exhibit 10-9 shows the effect of varying the value of time. The baseline value of time is assumed to be $11.20, as recommended by the DOT Office of the Secretary for local travel in vehicles for all purposes, personal and business. TERM values waiting and transfer times at $22.40 per hour double the value of in-vehicle travel time. (Departmental guidance on the value of time has not changed since the 2004 report, which also used these values.)

Overall, variations in the value of time have a very limited effect on projected investment estimates. Increases in the value of time increase the benefits of investment in transit modes that offer passenger travel times that are faster than nontransit modes, such as the automobile, and decrease the benefits of investment in transit modes with passenger travel speeds that are slower than nontransit modes. Hence, an increase in the value of time reduces projected investment in modes with relatively slower transit services (and some travel shifts from transit to automobiles) and increases projected investment in modes with relatively faster transit services (and some travel shifts from automobiles to transit). The opposite occurs in response to a decrease in the value of time.

Exhibit 10-9

Impact of Change in the Value of Time on Transit Investment Estimates by Scenario*

	Annual Cost to Maintain Conditions & Performance		Annual Cost to Improve Conditions & Performance	
Value of Time	**(Billions of 2004 Dollars)**	**Percent Change**	**(Billions of 2004 Dollars)**	**Percent Change**
Baseline	$15.75	–	$21.84	–
Increase 100%	$15.79	0.2%	$22.69	3.9%
Decrease by 50%	$15.81	0.4%	$21.69	-0.6%

*Investment estimates for rural and special service vehicles are included in the totals, but are not subject to the sensitivity analysis. They account for 5 percent or less of the total.

Source: Transit Economic Requirements Model.

Changes in User Cost Elasticities

"User cost" elasticity is the percentage change in ridership resulting from a 1 percent change in user costs. TERM uses user cost elasticities to estimate the changes in ridership that will result from changes in fare and travel time costs, due to infrastructure investment to increase speeds, decrease vehicle occupancy levels, and increase frequency. TERM assumes that these elasticities range from –0.22 to –0.40, depending on the mode. User cost elasticities are negative, reflecting an inverse relationship between ridership and costs. As ridership costs decrease, ridership increases. The larger the absolute value of the elasticity, the more responsive ridership will be to changes in user costs. As shown in *Exhibit 10-10*, a doubling or halving of these elasticities has almost no effect on projected investment scenarios.

Exhibit 10-10

Impact of Change in the Value of User Cost Elasticities on Transit Investment Estimates by Scenario*

	Annual Cost to Maintain Conditions & Performance		Annual Cost to Improve Conditions & Performance	
User Cost Elasticities	**(Billions of 2004 Dollars)**	**Percent Change**	**(Billions of 2004 Dollars)**	**Percent Change**
Baseline	$15.75	–	$21.84	–
Increase 100%	$15.75	0.0%	$22.80	4.4%
Decrease by 100%	$15.75	0.0%	$21.01	-3.8%

*Investment estimates for rural and special service vehicles are included in the totals, but are not subject to the sensitivity analysis. They account for 5 percent or less of the total.

Source: Transit Economic Requirements Model.